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DESCRIPTION

SOLID-STATE COLOR IMAGE PICKUP APPARATUS

TECHNICAL FIELD

The present invention relates to a progressive scan type solid-state color image pickup apparatus and, more particularly, to an arrangement of a color separation filter and a matrix calculation method for suppressing degradation in resolution of a luminance signal, which occurs when data from the color separation filter is subjected to matrix calculation. Further, the invention relates to a signal processing method for a solid-state color image pickup apparatus which obtains high resolution by performing interpolation between pixels. In this method, when a color-difference signal is composited from chrominance signals outputted from a solid-state image pickup device, the frequency characteristic of each chrominance signal is adjusted for each color of the color-separation filter to reduce a frequency component including aliasing which causes pseudo chrominance signals.

BACKGROUND ART

A video signal is usually represented by three primary colors of light: red (R), green (G), and blue (B), and it is also represented by luminance signals (Y) and two kinds of

color-difference signals (R-Y, B-Y). The three primary colors R, G, B usually take a form of an input signal to a monitor for a computer, and the luminance and color difference signals take a form of a digital part in a device such as a TV. Further, in recent years, a video signal from a solid-state color image pickup apparatus is used not only for image display but also for digital recording or video communication between devices. A video signal has a great amount of data, and usually it is compressed because of the limited recording capacity or communication capacity. A format of video signal employed in the video compression process is called 4:2:0 or 4:1:1 format in which chrominance data is reduced to half as compared with 4:2:2 format which has conventionally been employed.

Hereinafter, the conventional solid-state color image pickup apparatus will be described with reference to figure 2.

Figure 2(a) shows the conventional solid-state color image pickup apparatus, wherein 1 denotes an optical system for forming an image of a subject on the surface of a solid-state image pickup device; 2 denotes a solid-state image pickup device with a color separation filter for converting the image of the subject (optical image) to an image signal (electric signal); 3 denotes an AD converter for converting the image signal obtained by the solid-state image pickup device to a digital image signal; and 4 denotes an image signal processing circuit for converting the digital image signal to a luminance signal and

color-difference signals. Usually, a color separation filter having a checkered pattern of complementary colors shown in Figure 2(b) comprising magenta (Mg), green (G), cyan (Cy), and yellow (Ye) is used for the color separation filter placed on the surface of the solid-state image pickup device 2.

The operation of the solid-state color image pickup apparatus so constituted will be described hereinafter.

In Figure 2, the subject image (optical image) is formed on the solid-state image pickup device by the optical system 1. The solid-state image pickup device 2 outputs the subject image as an image signal which is color-separated by the color separation filter. The image signal is converted to a digital signal by the AD converter 3, supplied to the signal processing circuit 4, and converted to a luminance signal Y and two kinds of color-difference signals, whereby a color video signal is obtained. The image signal processing circuit generates a luminance signal (Y) and a pair of color-difference signals (R-Y, B-Y) corresponding to each pixel, from the four pixels of complementary colors Mg, G, Cy, and Ye.

An example of a procedure to generate luminance signals is as follows. Luminance signals $Y(h,v)$ are represented by

$$Y(0,0) = Mg(0,0)+G(1,0)+Cy(0,1)+Ye(1,1)$$

$$Y(1,0) = G(1,0)+Mg(2,0)+Ye(1,1)+Cy(2,1)$$

$$Y(0,1) = Cy(0,1)+Ye(1,1)+G(0,2)+Mg(1,2)$$

$$Y(1,1) = Ye(1,1)+Cy(2,1)+Mg(1,2)+G(2,2)$$

and thus four luminance signals are generated from the outputs of the solid-state image pickup device corresponding to the four pixels.

Likewise, color-difference signals R-Y (h,v) are represented by

$$R-Y(0,0) = Mg(0,0)-G(1,0)-Cy(0,1)+Ye(1,1)$$

$$R-Y(0,1) = -G(1,0)+Mg(2,0)+Ye(1,1)-Cy(2,1)$$

$$R-Y(1,0) = -Cy(0,1)+Ye(1,1)-G(0,2)+Mg(1,2)$$

$$R-Y(1,1) = Ye(1,1)-Cy(2,1)+Mg(1,2)-G(2,2)$$

and color-difference signals B-Y (h,v) are represented by

$$B-Y(0,0) = Mg(0,0)-G(1,0)+Cy(0,1)-Ye(1,1)$$

$$B-Y(0,1) = -G(1,0)+Mg(2,0)-Ye(1,1)+Cy(2,1)$$

$$B-Y(1,0) = Cy(0,1)-Ye(1,1)-G(0,2)+Mg(1,2)$$

$$B-Y(1,1) = -Ye(1,1)+Cy(2,1)+Mg(1,2)-G(2,2)$$

The number of the luminance signals Y, color difference signals R-Y, and color difference signals B-Y are equal to the number of pixels of the solid-state image pickup device, that is, these signals take the 4:4:4 format. According to a device to which these signals are applied, conversion to 4:2:2, 4:2:0, or 4:1:1 is carried out.

Moreover, since pseudo chrominance is generated at edges of luminance, edge judgement is performed according to edge signals from the composed luminance signals, and the gains of the color-difference signals corresponding to pixels decided as being edges are reduced to suppress the pseudo chrominance.

However, in the conventional solid-state color image pickup apparatus, no consideration is given to image compression, and it is premised that the output signals from the color separation filter are in the 4:4:4 format. So, three quarters of chrominance data become unnecessary when the output signals from the color separation filter are input to a device which is predicated on image compression of the 4:2:0 or 4:1:1 format. Moreover, each luminance signal is formed from four pixels. For example, when Y(0,0) and Y(0,1) shown in Figure 2 (b) are formed, since G(1,0) and Ye(1,1) are used for both of them, the luminance signals are not simply sampling data and are regarded as being passed through a low-pass filter in both of the vertical and horizontal directions. Therefore, the resolution is degraded as compared with a 3CCD type solid-state image pickup device performing pixel by pixel sampling. Also each color-difference signal is formed from adjacent four pixels and, therefore, it is not simple sampling data but is regarded as being passed through a low-pass filter in both of the vertical and horizontal directions, whereby the resolution is degraded as well.

In order to solve these problems, in a solid-state color image pickup apparatus according to the present invention, a color separation filter placed on the surface of a solid-state image pickup device has an arrangement pattern of four pixels corresponding to two whole-color-pass filters, one cyan-pass

filter, and one yellow-pass filter, and this arrangement pattern is repeated. The color separation filter so constructed outputs four pieces of luminance data, and two kinds of chrominance data each by one. Further, when converting them to luminance signals and color-difference signals, the relationship between a pixel for which an image of its subject is to be formed and its peripheral pixels is obtained by correlation detection, and pixels existing in the direction of higher correlation are used for operation.

Moreover, in the solid-state image pickup device according to the present invention, a plurality of chrominance signals are output from a plurality of color-pass filters. These chrominance signals are independent from color to color, and when attention is directed to a specific chrominance signal, its sampling rate is lower than the sampling rate of the whole signal. Therefore, there is a possibility that aliasing occurs in each chrominance signal, and the chrominance signal includes a frequency component having aliasing.

Figure 15 shows aliasing in the case where a specific chrominance signal is interpolated. In Figure 15, the abscissa shows the frequency and 2π indicates the sampling frequency of the whole signal, and the ordinate shows the signal amplitude. Further, the solid line shows the chrominance signal, and the dashed line shows the aliasing. When a color-difference signal is composited by interpolation using the chrominance signal

including a high-frequency component, an aliasing component is unfavorably included in the pass band up to $\pi/2$ as shown in Figure 15. This results in unsatisfactory interpolation precision, and causes a pseudo chrominance signal.

In order to solve the above problem, the solid-state color image pickup apparatus according to the present invention is provided with a frequency characteristic adjustment means which adjusts the frequency characteristic of each chrominance signal outputted from a solid-state image pickup device using a color separation filter composed of two whole-color-pass filters, one cyan-pass filter, and one yellow-pass filter, and a color-difference signal is composited by interpolation using the chrominance signals having the adjusted frequency characteristic.

Furthermore, the solid-state color image pickup apparatus of the present invention is provided with an edge decision function for correlation detection, whereby gains by which the color-difference signals are to be multiplied are decided, and the corresponding color-difference signals are multiplied by these gains, thereby reducing pseudo chrominance.

Accordingly, the present invention can provide a solid-state color image pickup apparatus with reduced deterioration of luminance resolution and reduced pseudo chrominance.

DISCLOSURE OF THE INVENTION

To solve the above-described problems, a solid-state color

image pickup apparatus defined in Claim 1 of the present invention comprises a solid-state image pickup device and a signal processing circuit. The solid-state image pickup device is provided with a color separation filter having one arrangement pattern comprising four pixels adjoining vertically and horizontally, said color separation filter of this arrangement pattern comprising two whole-color-pass filters corresponding to two pixels, a cyan-pass filter corresponding to one pixel, and a yellow-pass filter corresponding to one pixel, and repeating the arrangement pattern in the vertical and horizontal directions; and means for taking data corresponding to each pixel of the color separation filter. The signal processing circuit takes four luminance signals and two kinds of color-difference signals, for one of the arrangement patterns, from each pixel data taken out of the solid-state image pickup device and, at this time, the signal processing circuit generates two of the four luminance signals by using only the data from the whole-color-pass filters, and generates the remaining two luminance signals by using the data from the whole-color-pass filters and the data from peripheral pixels of the four pixels adjoining vertically and horizontally, and generates the two kinds of color-difference signals by using the data from the cyan or yellow-pass filter and the data from the peripheral pixels. Since two of the four luminance signals are generated from the data of the whole-color-pass filters, the

luminance resolution is improved.

Further, according to the invention defined in Claim 2, in the solid-state color image pickup apparatus defined in Claim 1, the color separation filter having one arrangement pattern comprising vertically and horizontally adjoining four pixels is constituted such that the four pixels are vertical two pixels × horizontal two pixels, and six signals comprising four luminance signals and two kinds of color-difference signals are generated from the data taken out of this arrangement pattern, and the six signals so generated are output to a device of 4:2:0 format. Thereby, the luminance resolution is improved in the device of 4:2:0 format.

Further, according to the invention defined in Claim 3, in the solid-state color image pickup apparatus defined in Claim 1, the color separation filter having one arrangement pattern comprising vertically and horizontally adjoining four pixels is constituted such that the four pixels are vertical one pixel × horizontal four pixels, and six signals comprising four luminance signals and two kinds of color-difference signals are generated from the data taken out of the arrangement pattern, and the six signals so generated are output to a device of 4:1:1 format. Thereby, the luminance resolution is improved in the device of 4:1:1 format.

Further, according to the invention defined in Claim 4, in the solid-state color image pickup apparatus defined in Claim 1,

the color separation filter having one arrangement pattern comprising vertically and horizontally adjoining four pixels, comprises a whole-color-pass filter and a cyan-pass filter for the upper two pixels from the left, and a yellow-pass filter and a whole-color-pass filter for the lower two pixels from the left, and the apparatus further comprises storage means for capturing a chrominance signal outputted from each pixel of the solid-state image pickup device, and storing it; correlation calculation means for calculating the correlation between a target pixel to be interpolated and plural pixels in the vicinity of the target pixel, said target pixel being any of a cyan signal pixel and a yellow signal pixel stored in the storage means; and interpolation means for interpolating the target pixel in a direction along which the calculated correlation is relatively large, and calculating a whole-color-pass signal in the position of the target pixel. Since an input image is converted to luminance signals after performing interpolation between pixels of high correlation, degradation of luminance resolution is suppressed.

Further, according to the invention defined in Claim 5, in the solid-state color image pickup apparatus defined in Claim 4, the correlation calculation means calculates the correlation between the target pixel and the pixels in the vicinity of the target pixel, including the target pixel, in the horizontal or vertical direction. Thereby, degradation of luminance

resolution is suppressed in the vertical direction and horizontal direction.

Further, according to the invention defined in Claim 6, in the solid-state color image pickup apparatus defined in Claim 4, the correlation calculation means calculates the correlation between the target pixel and the pixels in the vicinity of the target pixel, including the target pixel, in the horizontal or vertical direction and, further, in the diagonal direction. Thereby, degradation of luminance resolution is suppressed in the vertical direction, horizontal direction, and diagonal direction.

Further, according to the invention defined in Claim 7, in the solid-state color image pickup apparatus defined in Claim 4, the correlation calculation means calculates the correlation between the target pixel and the pixels in the vicinity of the target pixel, including the target pixel, in the horizontal or vertical direction and, further, in the upper right direction, or lower right direction, or upper left direction, or lower left direction. Thereby, degradation of luminance resolution is suppressed in the vertical direction, horizontal direction, upper right L-shaped direction, lower right L-shaped direction, upper left L-shaped direction, and lower left L-shaped direction.

Further, according to the invention defined in Claim 8, in the solid-state color image pickup apparatus defined in Claim 4, the correlation calculation means calculates the correlation

between the target pixel and the pixels in the vicinity of the target pixel, including the target pixel, in the horizontal or vertical direction, and in the diagonal direction, and further, in the upper right direction, or lower right direction, or upper left direction, or lower left direction. Thereby, degradation of luminance resolution is suppressed in the vertical direction, horizontal direction, diagonal direction, upper right L-shaped direction, lower right L-shaped direction, upper left L-shaped direction, and lower left L-shaped direction.

Further, according to the invention defined in Claim 9, in the solid-state color image pickup apparatus defined in Claim 4, the correlation calculation means calculates the correlation by performing operation on signals of the same color, between the target pixel and the pixels in the vicinity of the target pixel. Since the correlation is calculated between signals of the same color, the precision of correlation calculation is improved.

Further, according to the invention defined in Claim 10, in the solid-state color image pickup apparatus defined in Claim 4, the correlation calculation means calculates the correlation by performing operation on adjacent pixels being signals of different colors, between the target pixel and the pixels in the vicinity of the target pixel. Since the correlation is calculated between the target pixel and a pixel closest to the target pixel, even when these pixels are signals of different colors, the precision of correlation calculation is improved.

Further, according to the invention defined in Claim 11, in the solid-state color image pickup apparatus defined in Claim 4, the interpolation means performs interpolation using only signals of the same color as that of a chrominance signal to be generated, in the vicinity of the target pixel, without using the chrominance signal of the target pixel in the direction where the correlation calculated by the correlation calculation means is relatively large. Thereby, the interpolation precision is improved, and the luminance resolution is improved.

Further, according to the invention defined in Claim 12, in the solid-state color image pickup apparatus defined in Claim 4, the interpolation means calculates a shortage of a chrominance signal to be generated, from the pixels in the vicinity of the target pixel, using the chrominance signal of the target pixel in the direction where the correlation calculated by the correlation calculation means is relatively large, and performs interpolation on the shortage. Since only the shortage of chrominance component is interpolated while other components are interpolated using the chrominance signal component at the target pixel point, the interpolation precision is improved and the luminance resolution is prevented from being degraded.

Further, according to the invention defined in Claim 13, in the solid-state color image pickup apparatus defined in any of Claims 5 to 10, when the correlation calculated by the

correlation calculation means is smaller than a given threshold, said interpolation means reduces the gain of the color-difference signal corresponding to the pixel. Thereby, a pseudo chrominance signal generated at the edge of the luminance signal is reduced.

Further, according to the invention defined in Claim 14, in the solid-state color image pickup apparatus defined in any of Claims 5 to 10, when the correlation calculated by the correlation calculation means is smaller than a given threshold, said interpolation means reduces the gain of color-difference signal corresponding to the pixel, stepwise, according to the correlation. Thereby, a pseudo chrominance signal generated at the edge of the luminance signal is adaptively reduced.

Further, according to the invention defined in Claim 15, in the solid-state color image pickup apparatus defined in Claim 4, the interpolation means is provided with frequency characteristic adjustment means for adjusting the frequency characteristic of each chrominance signal outputted from the solid-state image pickup device, and the interpolation means interpolates and composites a color-difference signal by using the chrominance signal whose frequency characteristic is adjusted. Thereby, a pseudo chrominance signal, which appears when the color-difference signal is composited by interpolation using the chrominance signal containing high-frequency components, is reduced.

Further, according to the invention defined in Claim 16, in the solid-state color image pickup apparatus defined in Claim 5, the interpolation means is provided with frequency characteristic adjustment means for adjusting the frequency characteristic of each chrominance signal outputted from the solid-state image pickup device, and the interpolation means interpolates and composites an R-Y color-difference signal in the position of the cyan-pass filter, and a B-Y color-difference signal in the position of the yellow-pass filter, by using the chrominance signal whose frequency characteristic is adjusted. Thereby, a pseudo chrominance signal, which appears when the color-difference signal is composited by interpolation using the chrominance signal containing high-frequency components, is reduced.

Further, according to the invention defined in Claim 17, in the solid-state color image pickup apparatus defined in Claim 15, the interpolation means decides the correlation direction according to the correlation calculated by the correlation calculation means, performs frequency characteristic adjustment when there is a direction where the correlation is relatively large, and does not perform frequency characteristic adjustment when there is no direction where the correlation is relatively large. Thereby, the frequency component is retained when the color-difference signal is composited by interpolation using the chrominance signal having no correlation direction, whereby the

reproducibility of the color of image is maintained.

Further, according to the invention defined in Claim 18, in the solid-state color image pickup apparatus defined in Claim 16, the interpolation means decides the correlation direction according to the correlation calculated by the correlation calculation means, performs frequency characteristic adjustment when there is a direction where the correlation is relatively large, and does not perform frequency characteristic adjustment when there is no direction where the correlation is relatively large. Thereby, the frequency component is retained when the color-difference signal is composited by interpolation using the chrominance signal having no correlation direction, whereby the reproducibility of the color of image is maintained.

As described above, a solid-state color image pickup apparatus according to the present invention is provided with a solid-state image pickup device having, at its surface, a color separation filter comprising two whole-color-pass filters, one cyan-pass filter, and one yellow-pass filter corresponding to vertically and horizontally adjoining four pixels, and having a repetitive pattern of the four pixels; and a circuit for extracting four pieces of luminance data and two pieces of chrominance data from the four pixels as the repetitive pattern. Thereby, a superior solid-state color image pickup device having high luminance resolution and no degradation in the chrominance resolution is realized. Further, the above-mentioned apparatus

is further provided with means for capturing signals outputted from the respective pixels; correlation calculation means for calculating the correlation between a target pixel to be interpolated and plural pixels in the vicinity of the target pixel, said target pixel being any of a cyan signal pixel and a yellow signal pixel stored in the storage means; and means for performing interpolation in a direction along which the calculated correlation is relatively large, and calculating a whole-color-pass signal in the position of the target pixel. Thereby, it is possible to provide a solid-state color image pickup device which is able to reduce degradation in the luminance resolution, and realize the process of suppressing pseudo chrominance signals that appear at edges of the luminance signals, without adding a large-scale processing circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1(a) is a block diagram illustrating a solid-state color image pickup apparatus according to the present invention.

Figure 1(b) is a diagram illustrating a pattern of a color separation filter placed on the solid-state image pickup device shown in figure 1(a).

Figure 1(c) is a diagram illustrating a pattern of a color separation filter placed on the solid-state image pickup device shown in figure 1(a).

Figure 2(a) is a block diagram illustrating the

conventional solid-state color image pickup apparatus.

Figure 2(b) is a diagram illustrating a pattern of a color separation filter placed on the solid-state image pickup device shown in figure 2(a).

Figure 3(a) is a diagram illustrating the positions of luminance and color-difference signals in the 4:2:0 format, from a solid-state color image pickup apparatus according to a first embodiment of the present invention.

Figure 3(b) is a diagram illustrating the positions of luminance and color-difference signals in the 4:1:1 format, from a solid-state color image pickup apparatus according to a second embodiment of the present invention.

Figure 4 is a diagram illustrating an arrangement pattern of a color separation filter suitable for data output in the 4:2:0 format, according to the first embodiment of the present invention.

Figure 5 is a diagram illustrating an arrangement pattern of a color separation filter suitable for data output in the 4:1:1 format, according to the second embodiment of the present invention.

Figures 6(a) and 6(b) are diagram for explaining a solid-state color image pickup apparatus according to third to seventh embodiments of the present invention, wherein figure 6(a) shows the structure of the solid-state color image pickup apparatus, and figure 6(b) shows the structure of a color-separation filter

placed on the solid-state image pickup device.

Figure 7 is a diagram for explaining calculation of correlation, correlation directions (vertical and horizontal directions), and interpolation according to a sixth embodiment of the present invention.

Figure 8 is a diagram for explaining calculation of correlation, correlation directions (diagonal direction toward lower right and diagonal direction toward lower left), and interpolation according to a eighth embodiment of the present invention.

Figure 9 is a diagram for explaining calculation of correlation, correlation directions (four L-shaped directions), and interpolation according to a fifth embodiment of the present invention.

Figure 10 is a diagram for explaining the relationship between the correlation and the gain by which the color-difference signal is multiplied, according to a ninth embodiment of the present invention.

Figure 11 is a diagram for explaining the relationship between the correlation and the gain by which the color-difference signal is multiplied, according to the ninth embodiment of the present invention.

Figure 12 is a diagram illustrating the structure of a solid-state color image pickup apparatus according to a tenth embodiment of the present invention.

Figure 13 is a diagram for explaining the operation for adjusting the frequency characteristic, according to the tenth embodiment of the present invention.

Figure 14 is a diagram for explaining the operation for adjusting the frequency characteristic, according to the tenth embodiment of the present invention.

Figure 15 is a diagram for explaining the operation for adjusting the frequency characteristic, according to the tenth embodiment of the present invention.

Figure 16 is a diagram illustrating the structure of a solid-state color image pickup apparatus according to an eleventh embodiment of the present invention.

BEST MODE TO EXECUTE THE INVENTION

Hereinafter, embodiments of the present invention will be described.

Embodiment 1.

Hereinafter, a first embodiment corresponding to Claim 1 and Claim 2 of the present invention will be described.

Figure 1(a) illustrates a solid-state color image pickup apparatus according to the first embodiment of the invention. In the figure, reference numeral 1 denotes an optical system for forming an image of a subject on the surface of a solid-state image pickup, and it is composed of lenses and the like. Reference numeral 2 denotes a solid-state image pickup device

with a color separation filter, for converting the subject image (optical image) so formed to an image signal (electric signal). Reference numeral 3 denotes an AD converter for converting the image signal obtained by the solid-state image pickup device to a digital image signal. Reference numeral 4 denotes an image signal processing circuit for converting the digital image signal obtained by the AD converter to luminance signals and color-difference signals.

Figure 1(b) illustrates the color separation filter placed on the surface of the solid-state image pickup device 2 shown in figure 1(a). This filter has a repetitive pattern comprising vertical two pixels × horizontal two pixels. In the color separation filter, a whole-color-pass filter and a cyan-pass filter are arranged from the left for the upper two pixels, and a yellow-pass filter and a whole-color-pass filter are arranged from the left for the lower two pixels.

Figure 3(a) shows input/output signals to/from the image signal processing circuit 4 shown in Figure 1(a) according to the first embodiment.

In Figure 1(a), an image of the subject is formed on the surface of the solid-state image pickup device through the optical system 1, and the subject image (optical image) so formed is converted to an image signal (electric signal) by the solid-state image pickup device 2 with the color separation filter. Then, the image signal obtained from the solid-state

image pickup device is converted to a digital image signal by the AD converter 3, and the digital image signal obtained from the AD converter is converted to luminance signals and color-difference signals by the image signal processing circuit 4. Further, the color separation filter attached to the solid-state image pickup device 2 is constructed such that it repeats a pattern of vertical two pixels × horizontal two pixels as shown in figure 1(b), and the color separation filter having this pattern is composed of a whole-color-pass filter and a cyan-pass filter for the upper two pixels from the left, and a yellow-pass filter and a whole-color-pass filter for the lower two pixels from the left, that is, it has two whole-color-pass filters for the two pixels among the four pixels, and one cyan-pass filter and one yellow-pass filter for the remaining two pixels, respectively. In this case, four image signals are obtained from the solid-state image pickup device: two pieces of whole color data, one piece of cyan data, and one piece of yellow data. These four pieces of data are subjected to matrix operation to obtain four luminance signals, one R-Y color-difference signal, and one B-Y color-difference signal outputted from the image signal processing circuit 4.

Hereinafter, a description will be given of the operation of converting the digital image signal to luminance signals and color-difference signals by the image signal processing circuit 4, with reference to figure 3(a).

The respective color-pass filters are represented by the primary colors of light (red (R), green (G), blue (B)) as follows: W=R+G+G, Cy=G+B, and Ye=R+G. With respect to a luminance signal comprising all of the R, G, B components and located in a position where the whole-color-pass filter exists, this luminance signal is generated from only the signal from the whole-color-pass filter which is pure sampling data, and it is approximated as follows.

$$Y(h,v)=a\times W(h,v)$$

where a is a factor to adjust the dynamic range, and h+v is always an even number in the example of Figure 3(a).

Further, a luminance signal Y in a position where no whole-color-pass filter exists is generated using data of peripheral pixels as well, and it approximates as follows in a simple method.

$$Y(h,v)=a\times((W(h-1,v)+W(h+1,v)+W(h,v-1)+W(h,v+1))\div 4)$$

where a is a factor to adjust the dynamic range, and h+v is always an odd number in the example of Figure 3(a).

Further, a luminance signal Y in a position where the cyan-pass filter exists is generated by interpolation from peripheral pixels, utilizing the chrominance data in this position which is pure sampling data, since Cy has no R component among the luminance signal components, and it is approximated as follows.

$$R(h,v)=a\times (w(h-1,v)+w(h+1,v)+w(h,v-1)+w(h,v+1)\div 4$$

$-b \times (Cy(h,v) \times 4 + Cy(h-2,v) + Cy(h+2,v) + Cy(h,v-2) + Cy(h,v+2)) \div 8$

$Y(h,v) = b \times Cy(h,v) + R(h,v)$

A luminance signal Y in a position where the yellow-pass filter exists is generated by interpolation from peripheral pixels because Ye has no B component, and it is approximated as follows.

$B(h,v) = a \times (w(h-1,v) + w(h+1,v) + w(h,v-1) + w(h,v+1)) \div 4$

$-c \times (Ye(h,v) \times 4 + Ye(h-2,v) + Ye(h+2,v) + Ye(h,v-2) + Ye(h,v+2)) \div 8$

$Y(h,v) = c \times Ye(h,v) + B(h,v)$

where b and c are factors to adjust the dynamic range, h+v is always an odd number in the example of Figure 3, h and v in the position where the cyan-pass filter exists are an odd number and an even number, respectively, and h and v in the position where the yellow-pass filter exists are an even number and an odd number, respectively.

The luminance signal Y obtained from the Cy and Ye pixels is not regarded as being obtained from pure sampling data by the solid-state image pickup device, because the R and B components are generated by interpolation using the data of the peripheral pixels. However, the G+B component for the Cy pixel and the R+G component for the Ye pixel remain as pure sampling data, and the R and G components to be interpolated are only one third of the luminance signal Y at the maximum and, therefore, these components do not adversely affect the luminance signal Y, resulting in the luminance signal Y maintaining high resolution.

Furthermore, with respect to the color-difference signals (R-Y, B-Y), one piece of data is taken out for each color-difference signal for four luminance signals, and it is converted to R, G, B using, as a pattern, vertical two pixels $\times$ horizontal two pixels corresponding to the luminance signals, in a simple calculation method. The R and B components for conversion to the color-difference signals are represented as follows.

$$R(h,v)=a\times W((h \text{ div } 2)*2,(v \text{ div } 2)*2)-b\times Cy((h \text{ div } 2)*2+1, (v \text{ div } 2)*2)$$

$$B(h,v)=a\times W((h \text{ div } 2)*2+1,(v \text{ div } 2)*2+1)-c\times Ye((h \text{ div } 2)*2, (v \text{ div } 2)*2+1)$$

Further, the G component is represented as follows.

$$G(h,v)=a\times (W((h \text{ div } 2)*2,(v \text{ div } 2)*2)+W((h \text{ div } 2)*2+1, (v \text{ div } 2)*2+1))\div 2-R(h,v)-B(h,v)$$

According to these R, G, B, the color-difference signals are approximated as follows.

$$R-Y(h,v)=2\times R(h,v)-G(h,v)$$

$$B-Y(h,v)=2\times B(h,v)-G(h,v)$$

where a, b, and c are factors to adjust the dynamic range, div means a calculation which takes only the quotient obtained by division of integers and omits the remainder, and * means multiplication.

A pair of color-difference signals so obtained have improved chrominance resolution because the output of the solid-

state image pickup device is not used for adjacent other color-difference signals.

Through the above-mentioned operation, as shown in figure 3(a), two kinds of color-difference signals R-Y and B-Y are obtained, each by one, for four luminance signals Y corresponding to vertical two pixels × horizontal two pixels, and these signals are suitable as input signals to a device of the 4:2:0 format.

In addition, when the transmissivity of the whole-color-pass filter is set at 0.3 for R, 0.59 for B, and 0.11 for G, a pure luminance signal is obtained because the ratio of the transmissivities is equal to the mixing ratio of primary colors of the luminance signal Y, resulting in further improved resolution. That is, usually, the respective color-pass filters are expressed as follows with the primary color components (red, green, blue (R, G, B)): W=R+G+B, Cy=G+B, Ye=R+G. However, when the above-described setting is carried out, the RGB mixing ratio of the luminance signal Y is represented by

$$Y=0.30R+0.59G+0.11B$$

and the transmissivities of the respective color-pass filters used for this first embodiment are adjusted as follows.

$$W=0.30R+0.59G+0.11B$$

$$Cy=(0.59G+0.11B)\div 0.7$$

$$Ye=(0.30R+0.59G)\div 0.89$$

At this time, a luminance signal Y in a position where the

whole-color-pass filter exists is generated from the signal outputted from the whole-color-pass filter, which becomes pure sampling data, and this luminance signal is represented by

$$Y(h,v)=a\times W(h,v)$$

where a is a factor for adjusting the dynamic range, and h+v is always an even number in the example of Figure 3 (a). Further, a luminance signal Y in a position where no whole-color-pass filter exists is generated using data of peripheral pixels, in a simple method as follows.

$$Y(h,v)=a\times((W(h-1,v)+W(h+1,v)+W(h,v-1)+W(h,v+1))\div 4)$$

Further, utilizing the chrominance data in this position which is pure sampling data, a luminance signal Y in a position where the cyan-pass filter exists is generated as follows.

$$\begin{aligned}Y(h,v)=a&\times((W(h-1,v)+W(h+1,v)+W(h,v-1)+W(h,v+1))\div 4)\\&+0.7\times b\times(Cy(h-2,v)\div 2-(Cy(h+2,v)+Cy(h,v-2)\\&+Cy(h,v+2)+Cy(h,v))\div 8)\end{aligned}$$

Further, a luminance signal Y in a position where the yellow-pass filter exists may be generated as follows.

$$\begin{aligned}Y(h,v)=a&\times((W(h-1,v)+W(h+1,v)+W(h,v-1)+W(h,v+1))\div 4)\\&+0.7\times c\times(Ye(h-2,v)\div 2-(Ye(h+2,v)+Ye(h,v-2)\\&+Ye(h,v+2)+Ye(h,v))\div 8)\end{aligned}$$

where b and c are factors for adjusting the dynamic range, and h+v is always an odd number in the example of Figure 3 (a), h and v in the position where the cyan-pass filter exists are an odd number and an even number, respectively, and h and v in the

position where the yellow-pass filter exists are an even number and an odd number, respectively.

Moreover, with respect to the color-difference signals (R-Y, B-Y), one piece of data is taken out for each color-difference signal for four luminance signals, and the color-difference signals are obtained using, as a pattern, vertical two pixels × horizontal two pixels corresponding to the luminance signals, in a relatively simple calculation method as follows.

$$R\text{-}Y(h,v)=0.7\div 0.3\times(a\times(W((h \text{ div } 2)*2,(v \text{ div } 2)*2)$$
$$+W((h \text{ div } 2)*2+1,(v \text{ div } 2)*2+1))\div 2-b\times Cy((h \text{ div } 2)*2+1,$$
$$(v \text{ div } 2)*2))$$

$$B\text{-}Y(h,v)=0.89\div 0.11\times(a\times(W((h \text{ div } 2)*2,(v \text{ div } 2)*2)$$
$$+W((h \text{ div } 2)*2+1,(v \text{ div } 2)*2+1))\div 2-b\times Ye((h \text{ div } 2)*2,$$
$$(v \text{ div } 2)*2+1))$$

Alternatively, considering the sampling positions of the color-difference signals, the color difference signals may be obtained as follows.

$$R\text{-}Y(h,v)=0.7\div 0.3\times(a\times(W((h \text{ div } 2)*2,(v \text{ div } 2)*2)$$
$$+W((h \text{ div } 2)*2+1,(v \text{ div } 2)*2+1))\div 2-b\times(Cy((h \text{ div } 2)*2+1,$$
$$(v \text{ div } 2)*2)\times 2+Cy((h \text{ div } 2)*2-1,(v \text{ div } 2)*2)$$
$$+Cy((h \text{ div } 2)*2+1,(v \text{ div } 2)*2+2))\div 4)$$

$$B\text{-}Y(h,v)=0.89\div 0.11\times(a\times(W((h \text{ div } 2)*2,(v \text{ div } 2)*2)$$
$$+W((h \text{ div } 2)*2+1,(v \text{ div } 2)*2+1))\div 2-b\times(Ye((h \text{ div } 2)*2,$$
$$(v \text{ div } 2)*2+1)\times 2\ Ye((h \text{ div } 2)*2,(v \text{ div } 2)*2-1)$$

+Ye((h div 2)*2+2,(v div 2)*2+1))÷4

In this first embodiment, the whole-color-pass filters are arranged checkerwise. However, as shown in figure 4(a), in a repetitive pattern comprising vertical two pixels × horizontal two pixels, two whole-color-pass filters may be adjacent to each other in the horizontal direction, by arranging the two whole-color-pass filters for the upper two pixels, and a cyan-pass filter and a yellow-pass filter for the lower two pixels. In this case, the horizontal resolution is improved. Further, as shown in figure 4(b), two whole-color-pass filters may be adjacent to each other in the vertical direction, by arranging a whole-color-pass filter and a cyan-pass filter for the upper two pixels, and a whole-color-pass filter and a yellow-pass filter for the lower two pixels. In this case, the vertical resolution is improved. Further, the arrangement of the filters corresponding to the four pixels may be varied from pattern to pattern with the same effect as mentioned above.

Further, while in this first embodiment the color separation filter outputs signals in the 4:2:0 format, it can output signals in the 4:4:4, 4:2:2, or 4:4:1 format because the R, G, B components can be placed in any position by appropriately utilizing the peripheral pixels, although the chrominance resolution is somewhat degraded when performing conversion to the color-difference signals.

Further, while in this first embodiment the cyan-pass

filter and the yellow-pass filter are employed as filters other than the whole-color-pass filter, these filters may be a red-pass filter and a blue-pass filter. In this case, the calculation is simplified because there is no necessity of taking the R and B components from the filters. However, since the red-pass filter and the blue-pass filter include no green components, green components should be supplied from the peripheral pixels, whereby the luminance resolution is degraded.

Furthermore, in this first embodiment, the color separation filter having a pattern of vertical two pixels × horizontal two pixels is composed of a whole-color-pass filter and a cyan-pass filter for the upper two pixels from the left, and a yellow-pass filter and a whole-color-pass filter for the lower two pixels from the left. However, this arrangement may be changed without changing the colors (i.e., cyan and yellow) of the color-pass filters, or the combination of the colors of the color-pass filters may be changed from cyan and yellow to cyan and magenta, magenta and yellow, red and blue, red and green, or green and blue.

Embodiment 2.

Hereinafter, a second embodiment corresponding to Claim 1 and Claim 3 of the present invention will be described.

Figure 1(c) shows a color separation filter attached to the surface of the solid-state image pickup device 2 shown in figure 1(a). This filter has a repetitive pattern of vertical

one pixel × horizontal four pixels, and comprises a whole-color-pass filter, a cyan-pass filter, a whole-color-pass filter, and a yellow-pass filter which are arranged in this order from the left of the pattern.

Figure 3(b) shows input/output signals to/from the image signal processing circuit 4 shown in figure 1(a).

In figure 1(a), an image of a subject is formed at the surface of the solid-state image pickup device through the optical system 1, and the subject image (optical image) so formed is converted to an image signal (electric signal) by the solid-state image pickup device 2 with the color separation filter. Then, the image signal obtained from the solid-state image pickup device is converted to a digital image signal by the AD converter 3, and the digital image signal obtained from the AD converter is converted to luminance signals and color-difference signals by the image signal processing circuit 4. Further, as shown in figure 1(c), the color separation filter attached to the solid-state image pickup device 2 has a repetitive pattern of vertical one pixel × horizontal four pixels, and comprises, from the left, a whole-color-pass filter, a cyan-pass filter, a whole-color-pass filter, and a yellow-pass filter. That is, the color separation filter has two whole-color-pass filters for two pixels among four pixels, and a cyan-pass filter and a yellow-pass filter for the remaining two pixels. In this case, an image signal obtained from the solid-

state image pickup device comprises four pieces of data, i.e., two pieces of whole color data, one piece of cyan data, and one piece of yellow data. The image signal processing circuit 4 subjects these four pieces of data to matrix calculation, and outputs four luminance signals, one R-Y color-difference signal, and one B-Y color difference signal.

Hereinafter, a description will be given of the operation for converting the digital image signal to luminance signals and color-difference signals by the image signal processing circuit, with reference to figure 3(b).

The respective color-pass filters are represented by the primary color components of light (red (R), green (G), blue (B)) as follows: W=R+G+B, Cy=G+B, and Ye=R+G. A luminance signal Y in a position where the whole-color-pass filter exists, whose luminance data contains all of the R, G, B components, is generated from a signal outputted from the whole-color-pass filter which becomes pure sampling data, and it is approximated as follows.

$$Y(h,v)=a \times W(h,v)$$

where a is a factor to adjust the dynamic range, and h is always an even number in the example of Figure 3 (b).

Further, a luminance signal in a position where no whole-color-pass filter exists is generated using data of peripheral pixels, and it is approximated as follows in a simple generation method.

$$Y(h,v)=a\times((W(h-1,\ v)+W(h+1,V))\div 2)$$

where a is a factor to adjust the dynamic range, and h is always an odd number in the example of Figure 3 (b).

Moreover, effectively utilizing the chrominance data as pure sampling data in the corresponding position, a luminance signal Y in a position where the cyan-pass filter exists is generated by interpolation from peripheral pixels because the Cy has no R components, and it is approximated as follows.

$$R(h,v)=a\times((w(h-1,v)+w(h+1,v))\times 2+w(h-1,v-1)+w(h+1,v-1)$$
$$+w(h-1,v+1)+w(h+1,v+1))\div 8-b\times(Cy(h,v)\times 2+Cy(h,v-1)$$
$$+Cy(h,v+1))\div 4$$

$$Y(h,v)=b\times Cy(h,v)+R(h,v)$$

Further, a luminance signal Y in a position where the yellow-pass filter exists is generated by interpolation from peripheral pixels because the Ye has no B components, and it is approximated as follows.

$$B(h,v)=a\times((w(h-1,v)+w(h+1,v))\times 2+w(h-1,v-1)+w(h+1,v-1)$$
$$+w(h-1,v+1)+w(h+1,v+1))\div 8-c\times(Ye(h,v)\times 2+Ye(h,v-1)$$
$$+Ye(h,v+1)\div 4$$

$$Y(h,v)=c\times Ye(h,v)+B(h,v)$$

where b and c are factors to adjust the dynamic range, and mod means a calculation to take only the remainder obtained by division of integers, whereby h in the position where the cyan-pass filter exists becomes (h mod 4)=1, and h in the position where the yellow-pass filter exists becomes (h mod 4)=3.

The R and B components required for obtaining the above-described luminance signal Y from the Cy and Ye pixels are generated by interpolation using the data of the peripheral pixels and, therefore, the luminance signal Y is not regarded as being obtained from pure sampling data by the solid-state image pickup device. However, the G+B components for the Cy pixels and the R+G components for the Ye pixels remain as pure sampling data, and the R and G components to be interpolated are one third of the luminance signal Y at the maximum and do not adversary affect the luminance signal Y, resulting in the luminance signal Y maintaining high resolution.

With respect to the color-difference signals (R-Y, B-Y), one piece of data is taken out for each color-difference signal for four luminance signals and, in a simple calculation method, it is converted to R, G, B using, as a pattern, vertical one pixel × horizontal four pixels corresponding to the luminance signals. The R and B components for this conversion are represented by

$$R(h,v)=a\times W((h \text{ div } 4)*4,v)-b\times Cy((h \text{ div } 4)*4+1,v)$$

$$B(h,v)=a\times W((h \text{ div } 4)*4+2,v)-c\times Ye((h \text{ div } 4)*4+3,v)$$

and the G component is represented by

$$G(h,v)=a\times W((h \text{ div } 4)*4,v)+W((h \text{ div } 4)*4+2,v)\div 2-R(h,v)-B(h,v)$$

Using these R, G, B components, the color-difference signals are approximated as follows.

$$R-Y(h,v)=2\times R(h,v)-G(h,v)$$

$$B-Y(h,v)=2\times B(h,v)-G(h,v)$$

where a, b and c are factors to adjust the dynamic range.

A pair of color-difference signals so obtained have improved color resolution because the output of the solid-state image pickup device is not used for adjacent other color-difference signals.

Through the above-mentioned operation, as shown in figure 3(b), two kinds of color-difference signals R-Y and B-Y are obtained, each by one, for the four luminance signals Y corresponding to vertical one pixel × horizontal four pixels, and these signals are suitable as input signals to a device employing the 4:1:1 format.

In addition, when the transmissivity of the whole-color-pass filter is set at 0.3 for R, 0.59 for B, and 0.11 for G, a pure luminance signal is obtained because the ratio of the transmissivities is equal to the mixing ratio of primary colors of the luminance signal Y, resulting in further improved resolution. The transmissivities can be obtained by a calculation method similar to that described for the first embodiment although the matrix is different from that of the first embodiment.

Further, as described for the first embodiment, not only 4:1:1 output but also 4:4:4, 4:2:2, or 4:2:0 output can be achieved because the R, G, B components can be placed in any position by appropriately utilizing the peripheral pixels

although the chrominance resolution is somewhat degraded when performing conversion to the difference-color signals.

As shown in figure 5(a), the color-pass filters may be shifted by one pixel when the pattern of vertical one pixel × horizontal four pixels shown in figure 1(c) or 3(b) is repeated in the vertical direction so as to arrange the whole-color-pass filters checkerwise. In this case, the resolution of the luminance signal in the diagonal direction can be improved. Further, as shown in figure 5(b), the whole-color-pass filters and the color-pass filters other than the whole-color pass filters shown in figure 1(c) may be interchanged and, further, the cyan-pass filter and the yellow-pass filter may be interchanged, providing a repetitive pattern of 8 pixels. This filter arrangement provides improved chrominance resolution and is suitable for both of the 4:1:1 format (vertical one pixel × horizontal four pixels) and the 4:2:0 format (vertical two pixels × horizontal two pixels).

In this second embodiment, the color separation filter having a pattern of vertical one pixel × horizontal four pixels is composed of, from the left, a whole-color-pass filter, a cyan-pass filter, a whole-color-pass filter, and a yellow-pass filter. However, the arrangement of these filters may be changed without changing the colors (i.e., cyan and yellows) of the color-pass filters, or the combination of the colors of the color-pass filters may be changed from cyan and yellow to cyan

and magenta, magenta and yellow, red and blue, red and green, or green and blue. In the repetitive pattern of the color-pass filters corresponding to four pixels, when providing two whole-color-pass filters and two kinds of color-pass filters transparent to colors other than the whole color, the same effects as mentioned above are achieved. Further, four patterns of the color separation filter, each comprising vertical one pixel × horizontal four pixels, are provided in the vertical direction, and the arrangements of the color-pass filters in these four patterns may be different from each other.

Embodiment 3.

Hereinafter, a third embodiment corresponding to Claims 4, 5, 9, and 12 of the present invention will be described with reference to figures 6 and 7.

In figure 6(a), reference numeral 1 denotes an optical system for making an image of a subject on the surface of a solid-state image pickup device, and it is composed of lenses and the like. Reference numeral 2 denotes a solid-state image pickup device with a color separation filter, for converting the subject image (optical image) so formed to an image signal (electric signal). Reference numeral 3 denotes an AD converter for converting the image signal obtained from the solid-state image pickup device 2 to a digital image signal. Reference numeral 5 denotes a storage circuit for storing one frame of the digital image signal obtained in the AD converter 3. Reference

numeral 6 denotes a correlation calculation circuit for calculating the correlation between an arbitrary pixel of the digital image signal stored in the storage circuit 5, and peripheral pixels. Reference numeral 7 denotes an interpolation circuit for performing interpolation according to the correlation calculated by the correlation calculation circuit 6 to output luminance signals and color-difference signals. The luminance signals and the color-difference signals are generated by the optical system 1, the solid-state image pickup device 2 with the color separation filter, the AD converter 3, the storage circuit 5, the correlation calculation circuit 6, and the interpolation circuit 7.

Figure 6(b) shows the structure of the color separation filter placed on the solid-state image pickup device 2. This color separation filter has, as one unit of arrangement, four pixels adjacent to each other in the vertical and horizontal directions, and this arrangement unit is composed of a whole-color-pass filter and a cyan-pass filter for the upper two pixels from the left, and a yellow-pass filter and a whole-color-pass filter for the lower two pixels from the left. This arrangement unit is repeated in the vertical and horizontal directions.

The W pixel, Cy pixel, and Ye pixel captured in a storage circuit (not shown) are expressed by R, G, B components as follows: $W=(R+G+B)/3$, $Cy=(G+B)/3$, and $Ye=(R+B)/3$. When $W \fallingdotseq Y$,

the output signal corresponding to the W pixel can be expressed as a luminance signal. With respect to the Cy pixel and Ye pixel, the R and B components are obtained by interpolation and added to the Cy pixel and Ye pixel, respectively, whereby a luminance signal is expressed. Although signals corresponding to peripheral pixels are used for interpolation, the peripheral pixels used for interpolation are decided by calculating the correlation with a target pixel to be interpolated, by the correlation calculation circuit 6. Initially, the correlation calculating method will be described.

Figure 7 shows the arrangement of peripheral pixels when a cyan pixel Cyn is a target pixel. In figure 7, ● and ○ indicate Ye pixels and W pixels which are not used in the interpolation process for the pixel Cyn. Assuming that the correlation in the vertical direction (①-①' direction in figure 7) is Vc and the correlation in the horizontal direction (②-②' direction in figure 7) is Hc, these correlations Vc and Hc are calculated using the following expressions.

$$Vc=|Wu-Wd|+|Cyu-Cyn|+|Cyd-Cyn| \qquad (1)$$

$$Hc=|Wl-Wr|+|Cyl-Cyn|+|Cyr-Cyn| \qquad (2)$$

Using the result of the calculation, the correlation direction is decided according to the following conditional expressions.

$$Vc+Th < Hc \qquad (3)$$

$$Hc+Th < Vc \qquad (4)$$

wherein Th is a threshold, and this is a specific constant. The correlation direction is decided as the vertical direction when the expression (3) holds and as the horizontal direction when the expression (4) holds. When none of the expressions (3) and (4) holds, it is decided that there is no correction direction.

Next, the interpolation process will be described.

When the correlation direction is the vertical direction, a shortage component RCy is calculated using, as pixels for interpolation, only the peripheral pixels in the vertical direction with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wu+Wd)/2-(2*Cyn+Cyu+Cyd)/4 \quad (5)$$

When the correlation direction is the horizontal direction, a shortage component RCy is calculated using only the peripheral pixels in the horizontal direction with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wl+Wr)/2-(2*Cyn+Cyl+Cyr)/4 \quad (6)$$

When there is no correlation direction, a shortage component RCy is calculated using the peripheral pixels in both of the horizontal and vertical directions with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wu+Wd+Wl+Wr)/4-(4*Cyn+Cyu+Cyd+Cyl+Cyr)/8 \quad (7)$$

Using the shortage component RCy obtained by any of the expressions (5) to (7), the W component of the target pixel Cyn is obtained as follows.

W'=Cyn+RCy

For all of target pixels Cyn, W' is calculated by the above-described operation.

When the target pixel is a Ye pixel, Cy in the expressions (1) and (2) is replaced with Ye to calculate the correlation, and Cy in the right sides of the expressions (5) to (7) is replaced with Ye to obtain a shortage component BYe. Since the shortage component so obtained is not the R component but the B component, the W component of the Ye pixel can be obtained by W'=Yen+Bye. For all of the target pixels Yen, W' is calculated by the above-described operation.

In this interpolation process, the luminance W' of the Cy pixel and the luminance W' of the Ye pixel are obtained, whereby all of the luminance signals are obtained. In this method, the signals of the W pixels are used as they are, and the Cy pixels and Ye pixels are interpolated using the peripheral pixels having the higher correlation with them, whereby degradation in resolution is suppressed.

As described above, according to the third embodiment, the correlation between the target pixel to be interpolated and the peripheral pixels in the vertical and horizontal directions including the target pixel is detected, and the target pixel is interpolated using the correlation. Therefore, highly precise luminance signals are obtained, and the resolution is prevented from being degraded.

Embodiment 4.

Hereinafter, a fourth embodiment corresponding to Claim 6 of the present invention will be described with reference to figure 8.

The construction of this fourth embodiment is identical to that of the third embodiment. In this fourth embodiment, the correlation calculation circuit 6 calculates the correlation in the diagonal direction as well, and the interpolation circuit 7 performs interpolation using the correlation in the diagonal direction.

Hereinafter, the correlation calculating method will be described.

Figure 8 shows the arrangement of peripheral pixels when a cyan pixel Cyn is a target pixel to be interpolated. In figure 8, ● and ○ indicate Ye pixels and W pixels which are not used in the interpolation process for the pixel Cyn.

In the third embodiment of the invention, only the correlations in the ①-①' direction and the ②-②' direction are obtained as shown in figure 7. In this fourth embodiment, assuming that the correlation in the diagonal direction toward the lower right (the ③-③' direction in figure 8) is Nr, and the correlation in the diagonal direction toward the lower left (the ④-④' direction in figure 8) is Nl, and these correlations Nr and Nl are calculated using the following expressions.

$$Nr=|(Wu+Wl)/2-(Wd+Wr)/2|+|(Cyul-Cyn)|+|(Cydr-Cyn)| \quad (8)$$

$$Nl=|(Wu+Wr)/2-(Wd+Wl)/2|+|(Cydl-Cyn)|+|(Cyur-Cyn)| \quad (9)$$

Using the result of this calculation and the Vc and Hc obtained from the expressions (1) and (2), the correlation direction is decided according to the following conditional expressions.

$$Vc+Th < \min(Hc,Nr,Nl) \quad (10)$$

$$Hc+Th < \min(Vc,Nr,Nl) \quad (11)$$

$$Nr+Th < \min(Hc,Vc,Nl) \quad (12)$$

$$Nl+Th < \min(Hc,Vc,Nr) \quad (13)$$

wherein Th is a threshold (a specific constant), and min is a function which takes the minimum value among the elements in the parentheses. The correlation direction is the vertical direction when the expression (10) holds, the horizontal direction when the expression (11) holds, the diagonal direction toward the lower right when the expression (12) holds, and the diagonal direction toward the lower left when the expression (13) holds. When none of the expressions (10) to (13) holds, there is no correlation direction.

Next, the interpolation process will be described.

While in the third embodiment the interpolation process is described for the case where the correlation direction is decided as the vertical or horizontal direction and the case where there is no correlation direction, in this fourth embodiment the interpolation process in the case where the correlation direction is decided as the diagonal direction will

be added.

When the correlation direction is the diagonal direction toward the lower right, a shortage component RCy is calculated using only the peripheral pixels in the diagonal direction toward the lower right with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wu+Wd+Wl+Wr)/4-(2*Cyn+Cyul+Cydr)/4 \qquad (14)$$

When the correlation direction is the diagonal direction toward the lower left, a shortage component RCy is calculated using only the peripheral pixels in the diagonal direction toward the lower left with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wu+Wd+Wl+Wr)/4-(2*Cyn+Cyur+Cydl)/4 \qquad (15)$$

Thereafter, interpolation is performed in like manner as described for the third embodiment, thereby all of the luminance signals are obtained.

As described above, in this fourth embodiment, since interpolation is performed using not only the correlations in the vertical and horizontal directions but also the correlations in the diagonal directions, degradation of resolution is suppressed in the diagonal directions as well as in the vertical and horizontal directions.

Embodiment 5.

Next, a fifth embodiment corresponding to Claim 7 of the present invention will be described with reference to figure 9.

The construction of this fifth embodiment is identical to that of the third embodiment. In this fifth embodiment, the correlation calculation circuit 6 calculates the correlations in L-shaped directions as well, and the interpolation circuit 7 performs interpolation using the correlations in the L-shaped directions.

Initially, the correlation calculation method will be described.

Figure 9 shows the arrangement of peripheral pixels when a cyan pixel Cyn is a target pixel. In figure 9, ● and ○ indicate Ye pixels and W pixels which are not used in the interpolation process for the pixel Cyn.

In the third embodiment of the invention, only the correlations in the ①-①' direction and the ②-②' direction are obtained as shown in figure 7. In this fifth embodiment, assuming that the correlation in the upper left L-shaped direction (the ⑤-⑤' direction in figure 9) is Lul, the correlation in the upper right L-shaped direction (the ⑥-⑥' direction) is Lur, the correlation in the lower left L-shaped direction (the ⑦-⑦' direction) is Ldl, and the correlation in the lower right L-shaped direction (the ⑧-⑧' direction) is Ldr, and these correlations are calculated using the following expressions.

$$Lul=|Wu-Wl|+|Cyu-Cyn|+|Cyl-Cyn| \qquad (16)$$

$$Lur=|Wu-Wr|+|Cyu-Cyn|+|Cyr-Cyn| \qquad (17)$$

$$Ldl=|Wd-Wl|+|Cyd-Cyn|+|Cyl-Cyn| \qquad (18)$$

$$Ldr=|Wd-Wr|+|Cyd-Cyn|+|Cyr-Cyn| \qquad (19)$$

Using the result of calculation and the Vc and Hc obtained from the expressions (1) and (2), the correlation direction is decided according to the following conditional expressions.

$$Vc+Th < \min(Hc,Lul,Ldl,Lur,Ldr) \qquad (20)$$

$$Hc+Th < \min(Vc,Lul,Ldl,Lur,Ldr) \qquad (21)$$

$$Lul+Th < \min(Hc,Vc,Ldl,Lur,Ldr) \qquad (22)$$

$$Lur+Th < \min(Hc,Vc,Lul,Ldl,Ldr) \qquad (23)$$

$$Ldl+Th < \min(Hc,Vc,Lul,Lur,Ldr) \qquad (24)$$

$$Ldr+Th < \min(Hc,Vc,Lul,Ldl,Lur) \qquad (25)$$

where Th is a threshold (a specific constant), and min is a function which takes the minimum value among the elements in the parentheses. The correlation direction is the vertical direction when the expression (20) holds, the horizontal direction when the expression (21) holds, the upper left L-shaped direction when the expression (22) holds, the upper right L-shaped direction when the expression (23) holds, the lower left L-shaped direction when the expression (24) holds, and the lower right L-shaped direction when the expression (25) holds. When none of the expressions (20) to (25) holds, there is no correlation direction.

Next, the interpolation process will be described.

While in the third embodiment the interpolation process is described for the case where the correlation direction is the

vertical or horizontal direction and the case where there is no correlation direction, in this fifth embodiment the interpolation process in the case where the correlation direction is any of the above-mentioned L-shaped directions will be added.

When the correlation direction is the upper left L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the upper left L-shaped direction with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wu+Wl)/2-(2*Cyn+Cyu+Cyl)/4 \qquad (26)$$

When the correlation direction is the upper right L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the upper right L-shaped direction with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wu+Wr)/2-(2*Cyn+Cyu+Cyr)/4 \qquad (27)$$

When the correlation direction is the lower left L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the lower left L-shaped direction with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wd+Wl)/2-(2*Cyn+Cyd+Cyl)/4 \qquad (28)$$

When the correlation direction is the lower right L-shaped direction, a shortage component RCy is calculated using only the

peripheral pixels in the lower right L-shaped direction with respect to the target pixel Cyn, according to the following expression.

$$RCy=(Wd+Wr)/2-(2*Cyn+Cyd+Cyr)/4 \qquad (29)$$

Thereafter, interpolation is carried out in like manner as described for the third embodiment, whereby all of the luminance signals are obtained.

According to the fifth embodiment, as described above, not only the correlations in the vertical and horizontal directions but also the correlations in the respective L-shaped directions are detected to be used for interpolation. Therefore, degradation in resolution is suppressed in the L-shaped directions as well as in the vertical and horizontal directions.

Embodiment 6.

Next, a sixth embodiment corresponding to Claim 8 of the present invention will be described.

The construction of this sixth embodiment is fundamentally identical to that of the third embodiment. In this sixth embodiment, however, the correlation calculation circuit 6 calculates the correlations in the diagonal directions and the L-shaped directions as well as correlations in the vertical and horizontal directions, and the interpolation circuit 7 performs interpolation using the correlations in the diagonal directions and the L-shaped directions as well.

Initially, the correlation calculation method will be

described.

In the third embodiment, only the correlations Vc and Hc in the ①-①' direction and the ②-②' direction are obtained as shown in figure 7. In this sixth embodiment, more correlations as follows are obtained in like manner as described for the fourth and fifth embodiments: the correlation Nr in the diagonal direction toward the lower right (the ③-③' direction in figure 8), the correlation Nl in the diagonal direction toward the lower left (the ④-④' direction), the correlation Lul in the upper left L-shaped direction (the ⑤-⑤' direction in figure 9), the correlation Lur in the upper right L-shaped direction (the ⑥-⑥' direction), the correlation Ldl in the lower left L-shaped direction (the ⑦-⑦' direction), and the correlation Ldr in the lower right L-shaped direction (the ⑧-⑧' direction).

Using the results, the correlation direction is decided by the following conditional expressions.

$$Vc+Th < \min(Hc,Nr,Nl,Lul,Lur,Ldl,Ldr) \quad (30)$$

$$Hc+Th < \min(Vc,Nr,Nl,Lul,Lur,Ldl,Ldr) \quad (31)$$

$$Nr+Th < \min(Hc,Vc,Nl,Lul,Lur,Ldl,Ldr) \quad (32)$$

$$Nl+Th < \min(Hc,Vc,Nr,Lul,Lur,Ldl,Ldr) \quad (33)$$

$$Lul+Th < \min(Hc,Vc,Nr,Nl,Lur,Ldl,Ldr) \quad (34)$$

$$Lur+Th < \min(Hc,Vc,Nr,Nl,Lul,Ldl,Ldr) \quad (35)$$

$$Ldl+Th < \min(Hc,Vc,Nr,Nl,Lul,Lur,Ldr) \quad (36)$$

$$Ldr+Th < \min(Hc,Vc,Nr,Nl,Lul,Lur,Ldl) \quad (37)$$

where Th is a threshold (a specific constant), and min is a

function which takes the minimum value among the elements in the parentheses. The correlation direction is the vertical direction when the expression (30) holds, the horizontal direction when the expression (31) holds, the diagonal direction toward lower right when the expression (32) holds, the diagonal direction toward lower left when the expression (33) holds, the upper left L-shaped direction when the expression (34) holds, the upper right L-shaped direction when the expression (35) holds, the lower left L-shaped direction when the expression (36) holds, and the lower right L-shaped direction when the expression (37) holds. When none of these expressions (30) to (37) holds, there is no correlation direction.

Next, the interpolation process will be described.

While in the third embodiment the interpolation process is described for the case where the correlation direction is the vertical or horizontal direction and the case where there is no correlation direction, in this sixth embodiment the interpolation process in the case where the correlation direction is any of the above-mentioned diagonal directions and L-shaped directions will be added.

When the correlation direction is the diagonal direction toward the lower right, a shortage component RCy is calculated using only the peripheral pixels in the diagonal direction with respect to the target pixel Cyn, according to the expression (14). When the correlation direction is the diagonal direction

toward the lower left, a shortage component RCy is calculated using only the peripheral pixels in the diagonal direction with respect to the target pixel Cyn, according to the expression (15). When the correlation direction is the upper left L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the upper left L-shaped direction with respect to the target pixel Cyn, according to the expression (26). When the correlation direction is the upper right L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the upper right L-shaped direction with respect to the target pixel Cyn, according to the expression (27). When the correlation direction is the lower left L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the lower left L-shaped direction with respect to the target pixel Cyn, according to the expression (28). When the correlation direction is the lower right L-shaped direction, a shortage component RCy is calculated using only the peripheral pixels in the lower right L-shaped direction with respect to the target pixel Cyn, according to the expression (29).

Thereafter, interpolation is carried out in like manner as described for the third embodiment, whereby all of the luminance signals are obtained.

According to the sixth embodiment, as described above, not only the correlations in the vertical and horizontal directions

but also the correlations in the respective diagonal directions and L-shaped directions are detected to be used for interpolation. Therefore, degradation of resolution is suppressed in the diagonal directions and the L-shaped directions as well as in the vertical and horizontal directions.

Embodiment 7.

Next, a seventh embodiment corresponding to Claim 10 of the present invention will be described.

The construction of this seventh embodiment is identical to those of the third to seventh embodiments except the correlation calculating method by the correlation calculation circuit 6. In the third to sixth embodiments, the correlation Vc in the vertical direction, the correlation Hc in the horizontal direction, the correlation Nr in the diagonal direction toward the lower right, the correlation Nl in the diagonal direction toward the lower left, the correlation Lul in the upper left L-shaped direction, the correlation Lur in the upper right L-shaped direction, the correlation Ldl in the lower left L-shaped direction, and the correlation Ldr in the lower right L-shaped direction are obtained by operation using the pixels of the same color. In this seventh embodiment, however, these correlations are obtained by operation using adjacent pixels of different colors, according to the following expressions.

$$Vc=|Wu-Cyn|+|Wd-Cyn| \quad (38)$$

$$Hc=|Wl-Cyn|+|Wr-Cyn| \quad (39)$$

$$Nr=|(Wu+Wl)/2-Cyn|+|(Wd+Wr)/2-Cyn| \quad (40)$$

$$Nl=|(Wu+Wr)/2-Cyn|+|(Wd+Wl)/2-Cyn| \quad (41)$$

$$Lul=|Wu-Cyn|+|Wl-Cyn| \quad (42)$$

$$Ldl=|Wd-Cyn|+|Wl-Cyn| \quad (43)$$

$$Lur=|Wu-Cyn|+|Wr-Cyn| \quad (44)$$

$$Ldr=|Wd-Cyn|+|Wr-Cyn| \quad (45)$$

Decision on the correlation direction and interpolation are carried out in like manner as those mentioned for the third to sixth embodiments.

According to the seventh embodiment, since the correlations are obtained by operation between adjacent pixels of different colors, the precision in calculating the correlations is improved.

Embodiment 8.

Next, an eighth embodiment according to Claim 11 of the present invention will be described.

The construction of this eighth embodiment is identical to those of the third to sixth embodiments except the interpolation method by the interpolation circuit 7.

That is, in this eighth embodiment, when the target pixel Cyn obtained in any of the third to sixth embodiments is subjected to interpolation, the luminance W' of this target pixel Cyn is obtained using only the peripheral W pixels without using the pixel Cyn itself, according to the following

expressions.

When the correlation direction is the vertical direction,

$$W'=(Wu+Wd)/2 \tag{46}$$

When the correlation direction is the horizontal direction,

$$W'=(Wl+Wr)/2 \tag{47}$$

When the correlation direction is the upper left L-shaped direction,

$$W'=(Wu+Wl)/2 \tag{48}$$

When the correlation direction is the lower left L-shaped direction,

$$W'=(Wd+Wl)/2 \tag{49}$$

When the correlation direction is the upper right L-shaped direction,

$$W'=(Wu+Wr)/2 \tag{50}$$

When the correlation direction is the lower right L-shaped direction,

$$W'=(Wd+Wr)/2 \tag{51}$$

When the correlation direction is other than those mentioned above,

$$W'=(Wu+Wd+Wl+Wr)/4 \tag{52}$$

According to this eighth embodiment, since the luminance signals are calculated using only the W pixels, the interpolation precision is improved, resulting in a high-resolution image without luminance variations.

Embodiment 9.

Next, a ninth embodiment corresponding to Claims 13 and 14 of the present invention will be described with reference to figures 10 and 11.

In this ninth embodiment, when a target pixel to be interpolated is decided as having a correlation in a specific direction in the correlation detecting process according to any of the aforementioned embodiments, the color-difference signal (R-Y,B-Y) in the position of the target pixel is multiplied by a gain not larger than 1, regardless of the degree of the correlation.

Figure 10 shows the relationship between the degree of correlation in the direction which is decided as having the strongest correlation, and the gain by which the color-difference signal is to be multiplied. Although a pseudo chrominance signal tends to appear at the luminance edge, the pseudo chrominance can be suppressed when the interpolation circuit 7 has the function of multiplying the color-difference signal by a gain not larger than 1. Further, since the correlation detection circuit 6 may have the function of detecting the edge, the pseudo chrominance can be suppressed without providing a special luminance-edge detection circuit.

Further, the gain by which the color-difference signal is multiplied may be varied according to the degree of correlation in the direction decided as having the strongest correlation. Figure 11 shows an example of relationship between the degree of

correlation in the direction decided as having the strongest correlation and the gain by which the color-difference signal is multiplied. In this case, however, the stronger the correlation is, the smaller the degree of correlation is.

In figure 11, a width Thl is given to the correlation, and the gain by which the color-difference signal is multiplied is gradually decreased for each width Thl. Generally, the larger the difference in luminance at the edge is, the thicker the pseudo chrominance becomes. That is, since the possibility of generating thick pseudo chrominance is higher as the correlation is smaller, the level of the color-difference signal can be reduced according to the possibility, whereby the pseudo chrominance can be suppressed effectively.

Embodiment 10.

Hereinafter, a tenth embodiment corresponding to Claims 15 and 16 of the present invention will be described with reference to figures 12, 13, 14, and 15. In these figures, the same reference numerals as those used for the aforementioned embodiments denote the same or corresponding parts.

Figure 12 shows the structure of a solid-state color image pickup apparatus according to the tenth embodiment of the invention, and this is fundamentally identical to that shown in figure 6 except that a frequency characteristic adjustment circuit 10 is added to the structure of figure 6. The interpolation circuit 7 shown in figure 6 is separated into a

luminance signal interpolation circuit 8 and a color-difference signal interpolation circuit 9 in figure 12, and the frequency characteristic adjustment circuit 10 is inserted just before the color-difference signal interpolation circuit 9. The frequency characteristic adjustment circuit 10 adjusts the frequency of the image signal stored in the storage circuit 5, and outputs it to the color-difference signal interpolation circuit 9.

Figure 13 is a schematic diagram for explaining the operation of the frequency characteristic adjustment circuit 10 for restricting the frequency band to the low-pass band, and adjusting the frequency characteristic of the color-difference signal. The frequency characteristic adjustment using a low-pass filter can be performed in the vertical direction, the horizontal direction, the vertical and horizontal directions, and the diagonal direction. When using the low-pass filter in the vertical direction, 2n+1 (n=1,2,...) signals of the same color in the vertical direction with a target pixel (a pixel whose frequency characteristic is to be adjusted) in the center are used, and each signal is multiplied by a factor for deciding the filter characteristic, and the average of these signals is calculated. For example, in figure 13, when three signals of the same color in the vertical direction with the Cy23 as the target pixel are filtered by the low-pass filter, the output signal Cy23' from the frequency characteristic adjustment circuit 10 is represented as follows.

$$Cy23'=(Cy03+Cy23+Cy43)/3 \quad (53)$$

Likewise, when using the low-pass filter in the horizontal direction, 2n+1 (n=1,2,...) signals of the same color in the horizontal direction with a target pixel (a pixel whose frequency characteristic is to be adjusted) in the center are used, and each signal is multiplied by a factor for deciding the filter characteristic, and the average of these signals is calculated. For example, in figure 13, when three signals of the same color in the horizontal direction with the Cy23 as the target pixel are filtered by the low-pass filter with all of the factors being 1, the output signal Cy23' from the frequency characteristic adjustment circuit 10 is represented as follows.

$$Cy23'=(Cy21+Cy23+Cy25)/3 \quad (54)$$

Likewise, when using the low-pass filter in the vertical and horizontal directions, $(2n+1)\times(2m+1)$ (n,m=1,2,...) signals of the same color in the vertical and horizontal directions with a target pixel (a pixel whose frequency characteristic is to be adjusted) in the center are used, and each signal is multiplied by a factor for deciding the filter characteristic, and the average of these signals is calculated. For example, in figure 13, when nine signals of the same color in the vertical and horizontal directions with the Cy23 as the target pixel are filtered by the low-pass filter with all of the factors being 1, the resultant signal is represented as follows.

$$Cy23'=(Cy01+Cy03+Cy05+Cy21+Cy23+Cy25+Cy41+Cy43+Cy45)/9 \quad (55)$$

Likewise, when using the low-pass filter in the diagonal directions, 2n+2m+1 (n,m=1,2,...) signals of the same color in the vertical and horizontal cross-shaped directions with a target pixel (a pixel whose frequency characteristic is to be adjusted) in the center are used, and each signal is multiplied by a factor for deciding the filter characteristic, and the average of these signals is calculated. For example, in figure 13, when five signals of the same color in the vertical and horizontal cross-shaped directions with the Cy23 as the target pixel are filtered by the low-pass filter with all of the factors being 1, the resultant signal is represented as follows.

$$Cy23'=(Cy03+Cy21+Cy23+Cy25+Cy43)/9 \quad (56)$$

The above-described operation for adjusting the frequency characteristic is performed on all of the chrominance signals which are required for compositing the color-difference signal by interpolation.

For example, when compositing the color-difference signal using the Cy23 as the target pixel and the W22 and W24 as the peripheral pixels, in order to apply the low-pass filter in the vertical and horizontal directions, the chrominance signals required for interpolation are calculated as shown in the following expressions (57), (58), and (59).

$$W22'=(W00+W02+W04+W20+W22+W24+W40+W42+W44)/9 \quad (57)$$

$$Cy23'=(Cy01+Cy03+Cy05+Cy21+Cy23+Cy25+Cy41+Cy43+Cy45)/9 \quad (58)$$

$$W24'=(W02+W04+W06+W20+W22+W24+W26+W42+W44+W46)/9 \quad (59)$$

In the color-difference signal interpolation circuit 9 shown in figure 12, the R-Y color-difference signal is calculated using the Cy23', W22', and W24' according to the following expression.

$$R-Y=A\times(W22'+W24')-B\times Cy23' \qquad (60)$$

wherein A and B are constants depending on the white balance or the like. Further, when the Ye pixels are subjected to the above-described frequency characteristic adjustment and color-difference signal compensation using the same positional relationship as described above, the B-Y color-difference signal can be obtained.

Figure 14 shows the amplitude characteristics 11 using three-point averaging as a method of frequency characteristic adjustment for the chrominance signal, and the amplitude characteristics 12 using linear interpolation as a method of interpolation for the color-difference signal, and these characteristics combined are shown by the solid line. The abscissa shows the frequency, and the sampling frequency of each chrominance signal is indicated by π. As shown in figure 14, when linear interpolation is performed using the chrominance signal subjected to frequency characteristic adjustment, the frequency component including aliasing, which appears in the vicinity of $\pi/2$ of the chrominance signal (shown by the dashed line in figure 15), is reduced.

In this tenth embodiment, when the chrominance signal

stored in the storage circuit 5 contains high frequency components, the frequency characteristic adjustment circuit 10 reduces the frequency component including aliasing, and the color-difference signal interpolation circuit 9 composites the color-difference signal by interpolation using the chrominance signal whose frequency characteristic is adjusted, whereby the pseudo chrominance signal is reduced.

Embodiment 11.

Hereinafter, an eleventh embodiment corresponding to Claims 17 and 18 of the present invention will be described with reference to figure 16. In figure 16, the same reference numerals as those used for the aforementioned embodiments denote the same constituents.

Figure 16 shows the structure of a solid-state color image pickup apparatus according to the eleventh embodiment, and it is fundamentally identical to the structure shown in figure 12 except that the frequency characteristic adjustment circuit 10 is controlled by the output from the correlation detection circuit 6.

In this construction, when the correlation detection circuit 6 decides that there is a correlation direction, the frequency characteristic of the chrominance signal of a target pixel to be interpolated is adjusted by the frequency characteristic adjustment circuit 10. Further, using the color signal of the target pixel whose frequency characteristic is

adjusted, the color-difference signal is calculated by the color-difference signal interpolation circuit 9. This process is identical to that mentioned for the tenth embodiment.

On the other hand, when the correlation detection circuit 6 decides that there is no correlation direction, the chrominance signal of the target pixel is sent to the color-difference signal interpolation circuit 9 without being processed in the frequency characteristic adjustment circuit 10. In the interpolation circuit 9, the color-difference signal is calculated using the chrominance signal and the luminance signal from the luminance signal interpolation circuit 8.

As described above, in this eleventh embodiment, the frequency characteristic of the chrominance signal including high-frequency components and having the correlation direction is adjusted by the frequency characteristic adjustment circuit 10, whereby occurrence of pseudo chrominance signals is reduced. On the other hand, since the chrominance signal having no correlation direction does not include pseudo chrominance components inherently, this chrominance signal need not be subjected to adjustment of frequency characteristic, and so the frequency components of the chrominance signal are not attenuated by adjustment of frequency characteristic, whereby the color reproducibility is maintained.

APPLICABILITY IN INDUSTORY

As described above, in the solid-state color image pickup apparatus according to the present invention, four pieces of luminance data and two pieces of chrominance data are taken out of vertically and horizontally adjacent 4 pixels of the color separation filter placed on the surface of the solid-state image pickup device, whereby the luminance resolution is improved, and degradation of chrominance resolution is reduced. Therefore, this is valuable as a signal processing method of the solid-state color image pickup apparatus which obtains high resolution by performing interpolation between pixels.